INVESTIGATION OF SENSITIZATION OF BRITTLE COATINGS

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OBJECT

This work has been experimental in character. The authors felt that a research thesis would be of greater interest and value than one of pure design since much design work has been covered in the classroom. This research problem was approached with two general objectives in view: first, to learn and to understand the problems and procedures connected with any research problem; and second, to investigate some problem, the solution of which might prove useful in the scientific field.

This subject was picked to give a feeling of pioneering in an undeveloped field. As far as the authors can ascertain, no experimental results have been published on the subject of sensitization of brittle coatings. G. Ellis advances the claim that "If dye etchant is applied to the surface of the brittle coating while the structure is under load, the coating will be sensitized by 0.0006 in/in strain..... Where there is no appreciable stress on the surface, the dye etched patterns will appear as haphazard craze marks. However, where there is any appreciable amount of strain the craze marks will straighten themselves out into a definite pattern."(1) Also, " The results obtained by sensitization are to be considered wholly qualitative in character, their primary function being to obtain diredtion of principal stresses"(2).

In the field of stress analysis, if this sensitivity of the brittle coating could be increased such that it would be possible to read strains of the order of 0.0002 in/in with consistency, it would greatly aid and encourage the use of the brittle coating method of stress analysis. The general objectives have been stated, but the specific investigation isto check the manufacturer's claim for the

effectiveness of dye etching under load and to undertake a comprehensive investigation of the effect of heat treatment.

The authors will draw conclusions from the results and will make suggestions for the continuation of the work. Any irregularities that appear will be accompanied by explanations of the probable causes.

THEORY AND USE OF BRITTLE COATINGS

In 1932, the German scientists Dietrich and Lehr published the first recognized work on the use of brittle coatings for the indication of strains in the elastic range. In 1937, the first major investigation in this country was conducted by G. Ellis of Massachusetts Institute of Technology, and since that date there have been many improvements and modifications of the original technique, materials, and equipment. Of the many brittle materials which might be applied to stress measurement, the one most used today is a brittle resin in volatile solvent type lacquer material. The most widely used coating is a proprietary solution called "Stresscoat" which is manufactured by Magnaflux Corporation.

The coating is applied to the surface to be investigated by spraying rather than dipping or brushing because spraying is easier, and also because the peculiar property that small bubbles included into the coating improve the quantitative accuracy of the strain pattern formation. Best drying time is 18 to 24 hours. Stressing the surface of a structure by adding load causes the brittle coating to fracture when a certain critical value of tension strain is reached. From a quantitative standpoint, this critical value of the strain which just initiates pattern formation is the most important measurement which can be made with a brittle coating. Patterns run at right angles to the principal tension stress. "The brittle coating may be thought of as providing a large number of principal tension strain indicators with a minimum gauge length of 0.05 inch and with a workable range of approximately 0.0007 to 0.0012 in/in strain."(3)

Quantitative evaluation of the amount of strain is secured by calibration. A calibration strip of spring steel 12"x1"x¼" is sprayed and dried along with the structure under test. The most convenient

method of calibration devised is a cantilever beam under known deflection loading. The loading rig (fig. 6 and 7) embodies an adjustment screw at the fixed end to bring the strip in contact with the cam and a cam of definite deflection. This deflection is such that the upper surface of a coating 0.004 inch thick on the test strip will receive the graduated amount of strain along the strip from a maximum at the fixed end to zero under the cam. The testing procedure is simply to place the coated and dried strip in the loading rig, adjust the strip so that it will just touch the bottom of the cam, and deflect the cam to its full extent. Reference marks can be made on the strip opposite the characteristic patterns being investigated. After release from the calibrator, the calibration strip is placed in a strain scale (fig. 8) which is marked off in terms of the strain imposed on the strip by the fixed cam deflection. Evaluation of the strains on a structure is made by matching the regularity of the crack patterns on the structure and on the calibration strip rather than by counting the number of lines per inch.

"Since the range of strain which can be evaluated is smaller than the range present on most structures another principle must be utilized in order to effect a complete analysis. If the assumption is made that Hooke's Law holds over the entire structure, then local strains at different values of loading on the structure can be measured and by simple proportion one can interpolate or extrapolate all local strains to correspond to any value chosen. In general Hooke's Law is a good approximation to actual performance, and, in practice, structures which seriously deviate from it are fairly easy to recognize."(3)

"On areas of moderate strain concentration values of principal tension and compression strains may be estimated within an error of about fifteen percent. The direction of the principal strains is indicated with exceptional precision."(3)

Despite their brittleness the coatings are quite plastic, and the amount of strain necessary to crack a coating varies with the time taken to reach the load. Correction for creep is therefore an important factor in obtaining quantitative measurements. Correction may be had either by loading all bodies involved in the test in the same length of time, or else by loading at a constant rate, observing the time at which patterns first appear, and correcting all values to a common time of loading by means of a chart of creep curves (fig. 2).

The main disadvantage of Stresscoat is that the resin materials are sensitive to temperature variations and therefore should be used where the temperature does not vary more than 5°F during the loading cycle. Because the coatings are so sensitive to temperature and humidity, it is necessary to use different coatings to obtain the same degree of sensitivity (i.e., the amount of strain necessary to initiate pattern formation) under different weather conditions prevailing on different tests. For various temperatures and humidities the manufacturers of Stresscoat have developed a series of numbered coatings, and for a given temperature and humidity condition there is a certain optimum coating. Over twenty coatings are available, so that for any weather condition there are coatings of several strain sensitivities.

A uniformly bright background is a great help in observing the stress pattern easily. It also aids in applying the brittle coating by supplying a uniform background against which the thickness of the brittle coatings gives a characteristic color. An aluminum pigmented undercoating provides an excellent background. It is possible to apply the undercoating and have it dry sufficiently within fifteen minutes to cause no adverse effect on the brittle coating.

A red dye etchant solution serves several useful purposes.

Formulated of solvent with a heavy concentration of organic dyes, the etchant reacts on the surface of the brittle coating in a manner similar to acid on steel. The organic solvent etchant preferentially attacks any cracks whether visible or invisible to the eye. The red dye helps to delineate the pattern by working its way into the strain pattern and colloring the cracks red. This is especially helpful for making photographs of the pattern because the contrast is not sufficient when the piece has not been dye etched. In the OBJECT the authors have included another use for dye etchant recommended by the manufacturer, the use of the etchant to sensitize the coating.

The following is an outline of the usual steps in an ordinary Stresscoat analysis:

PREPARE SURFACE.

Remove loose scale, grease, and paint.

APPLY UNDERCOATING.

Spray aluminum undercoating on structure to be investigated and on calibration strips. Allow 15 minutes to dry before proceding.

SELECT COATING.

In order to obtain satisfactory results and know the quantity of strain indicated by the initial formation of strain patterns, it is necessary both to select the proper coating and to calibrate it for every test. Coatings are selected for conditions prevailing at the time and place where drying and testing will be done. The wet and dry bulb temperatures are measured by means of a sling psychrometer. Using these readings the proper coating is selected from the Coating Selection Chart (fig. 1). The coating number which lies in the space between two curves where the intersection of the two temperatures falls is the optimum coating and is best for average use. This coat will

have a sensitivity of 0.0007 to 0.0008 in/in. Each coating under its designated or optimum conditions acts the same as all others under their optimum conditions. If a more sensitive coating is desired, the next higher number coating should be used. Conversely, lower number coatings will be less sensitive.

APPLY COATING.

Stresscoat is applied by spraying. The nozzle is held two to five inches from the work, and the gun is moved parallel to the work. As the spraying progresses, the color of the coating changes from apparently clear to a definite yellow to a light brown. The yellow tinge indicates the most desiracle thickness, from 0.003 to 0.006 inch.

DRY COATING.

The structure and calibration strips are dried together under as near the same conditions as possible. Minimum drying time is six hours.

TEST STRUCTURE AND CALIBRATION STRIP.

Calibration strip is placed in the calibrator and loaded by the cam as previously explained. The load is removed and the strip is placed in the strain scale. The value of strainaat the lowest pattern is the sensitivity. The structure is loaded and tested as desired, and the strain on the structure at the lowest pattern is the same as that on the calibration bar. Creep correction is made either by loading the calibration strip in the same length of time taken to apply the load on the structure or by loading the calibration strip in one second and correcting for the actual loading time by use of the creep correction chart (fig. 2).

DYE ETCHING

Dye etch after completion of test by brushing on etchant, wiping it off after one minute, and washing strip with etchant emulsifier. This enables results to be read more easily and more accurately, and also permits photographing the pattern.

The above is standard procedure. Any deviation from this technique by the authors will be discussed in another section.

PROCEDURE

Before any tests were made, it was necessary to construct twelve extra calibration strips. They were made of spring steel 12"x1"x$\frac{1}{4}$", an exact copy of the calibration strips furnished with the Stresscoat equipment. After becoming fairly proficient in the use of the spray gun, the authors began the test of the dye etchant.

TEST 1.

The optimum coating was found to be 1205. Six strips were sprayed with this coat, three with 1203, and three with 1207. The coatings above and below optimum were tested to find the effect of the etchant on more and less sensitive coatings. The strips were placed in a cabinet to dry unaffected by air currents. After drying 24 hours, the bars were tested in the calibration rig according to the procedure set forth in the preceding section. While the bars were loaded, the lowest crack was marked and dye etchant applied. After all bars were stressed, marked, and etched, they were placed in the strain gauge and the readings recorded.

Viewed through a magnifying glass under strong light, faint craze marks oriented normal to the direction of principal stress were found in the etched specimens. The ends of these marks were very difficult to distinguish, and their value on complicated shapes seems questionable. The recorded value of sensitivity after etching is quite arbitrary. The sensitivity was increased from 0.0002 to 0.0004 in/in, and this process might have some qualitative value even though the quantitative results seem unreliable. The lowest sensitivity was found in the coat of 1207 as was to be expected, and the value was approximately 0.0004 in/in strain.

TEST 2.

From the results of Test 1 the authors concluded that only optimum and higher numbered coatings should be used in further attempts to increase sensitivity by dye etching. Consequently, Test 2 was made with optimum coat 1205, 1207 and 1209. The drying and testing followed the same procedure as Test 1, and the results compared favorably with the results of that test. Dispersion is greater with the more sensitive higher numbered coatings, and the drying craze (as shown in fig. 9) made readings more difficult.

TEST 3.

This test was run as before, but coatings used were optimum 1206, 1208, and 1211, and two specimens of coat 1206 were dried 24 hours in the oven at 100 F. The heattreated bars were removed from the oven, cooled in still air for 1 minute and 15 minutes respectively before testing. All bars were etched under load as before.

The air dried coatings compared well with those in preceding tests, but the specimens dried in the oven had a remarkable increase in sensitivity. Since the two cooling times differed so in sensitivity, the authors felt that the next test should be to determine the optimum drying time if such existed. In the 1 minute cooling time the coating had not reached room temperature, and after 15 minutes the equilibrium must have been more nearly approached.

The readings after etching were even more difficult to make than before. The etching time decreased markedly, and the etchant seemed more active on the baked coat although the amount of sensitivity increase was about the same as with air dried coatings. The coating which was baked and cooled 15 minutes gave a sensitivity of 0.00045 before etching and 0.00025 after etching.

TEST 4.

The optimum coating was found to be #1206. Twelve bars were prepared with this coating. Two were dried at room temperature for a standard, and ten were placed in the oven at 100 F. After 24 hours, the heated bars were removed and stressed after different times of cooling. Times used were 0, 2, 4, 5, 6, 8, 10, 12, and 14 minutes. The air dried bars were also stressed, and all bars were etched under load. The specimens tested immediately on removal from the oven were of approximately the same sensitivity as those dried at room temperature, and the sensitivity definitely increased as the time of cooling increased. The curve of Sensitivity vs. Time of cooling (fig. 3) seems to level off after about 6 minutes, and longer times show little or no increase.

TEST 5.

The optimum coating was found to be #1207. Six bars were prepared with this coating and six with 1209. Two of each were air dried, and the remainder dried in the oven at 100 F for 24 hours. The four baked specimens of coat 1207 were removed and stressed after cooling in still air for periods of 0, 10, 20, and 30 minutes, and those of 1209 were removed and tested after cooling for periods of 0, 5, 10, and 15 minutes. The results confirmed those of Test 4, except that the optimum period for cooling seems to be longer - about 15 minutes. The specimen of 1209 which cooled 15 minutes showed a critical strain of 0.00035, and the etching craze was off the scale.

TEST 6.

The optimum coating was found to be #1208, and twelve bars

TEST 6 cont.

were prepared with that coating. Two strips were air dried, and ten were dried in the oven at 100 F for 24 hours. The specimens were removed from the oven and cooledin still air at various rates in another effort to find the optimum time of cooling. Cooling periods used were 0, 3, 6, 9, 12, 15, 20, 25, 30, and 40 minutes. The cooling curve (fig. 4) shows the optimum time to be about 15 or 20 minutes. This coating gave the most sensitive specimen yet found. The strain gauge is calibrated only down to 0.0004 in/in and by extrapolating, these coatings were found to have critical strains of the order of 0.0002 in/in. For this reason and also to gain accuracy, the authors constructed a new cam for the calibration rig. Since the strain in a cantilever is directly proportional to the deflection, a cam giving half the deflection of the old cam would produce half the strain at any given point on the strip. A cam was made with one-half the eccentricity of the old cam, placed in the rig, and by means of deflection gauge, deflections were checked at points along the bent bar to prove that the deflection of any point had been halved. A value now read in the strain gauge is twice the true value of the strain on the bar at that point, and the range of the scale was now from 0.0002 to 0.0010 in/in. This new cam was used in all tests to follow.

TEST 7.

With the optimum coating 1207, twelve bars were prepared with 1209, and two dried at room temperature while the other ten were dried in the oven at 100 F for 24 hours. The oven-dried specimens were cooled for periods of 0, 3, 6, 9, 12, 15, 20, 25, 30, and 40 minutes to find the optimum cooling time for this coating. As with Test 6, the cooling curve for this test (fig. 5) shows the optimum time of cooling to be

TEST 7 cont.

about 20 minutes. After this time the coating seems to be stable, and further cooling does not affect the sensitivity. The heat treatment increased the sensitivity from about 0.0010 in/in when air dried to about 0.0002 in/in when dried at 100 F and cooled to equilibrium. The accuracy of the strain gauge is much increased with the new cam of smaller eccentricity.

TEST 8.

Since the results obtained from heat treatment were so encouraging, and the results from dye etching under load were so discouraging, the authors deemed it expedient to turn their efforts entirely to the effect of heat treatment, and Test 7 was the last test where dye etching under load was used.

With the results from 100 F obtained, Test 8 was used to investigate the effect of a highertemperature of 120 F. The optimum coat 1206 was used as well as coat 1208. For any practical use, 1206 was found to be the better at this temperature with air cooling. While 1208 was more sensitive and gave less dispersion, the accompanying craze would make readings on a more complicated structure extremely difficult to determine. All readings were taken after cooling for a period of 20 minutes or more.

TEST 9.

It was decided that an investigation of other temperatures was in order, and the next chosen was 90 F. To give a comprehensive picture of the effect of the temperature used, four coatings were prepared: 1206, 1208, 1209, and 1211 with 1208 being optimum. In spraying

TEST 9 cont.

these coats, it was found that the higher numbered coats were much more difficult to apply, mainly because they tended to dust unless the spray gun was held extremely close to the work. The lower numbered coats of 1206 and 1208 were relatively easy to apply, and it was possible to get a much more even and satisfactory coating with the lower numbered coats. The effect of 90 F was relatively small, giving perhaps a small increase in the sensitivity. Since the effect was so small, the remainder of the investigation was conducted at temperatures of 100 F or higher.

TEST 10.

The same four coats were used as in test 9, with 1208 again the optimum coat. A drying temperature of 110 F was used with air cooling. 1208 was the best coat. 1211 crazed so that a reading was impossible. 1209 was less sensitive than 1208, and it is believed that this was due to use of an old can of lacquer 1209.

TEST 11.

The series of four coats had not been tested at 100 F, and this was selected for Test 11. Coat 1207 was optimum for this test. All specimens were cooled in still air for 20 minutes, and 1211 gave the lowest critical strain with no crazing.

TEST 12.

It was desired to duplicate if possible the results of Test 6 and to prepare a curve of the effect of cooling time on sensitivity. This was done with the optimum coat of 1208, and a drying temperature of 100 F. The results confirmed those of Test 6 except as noted, and the curve of sensitivity vs. cooling time (fig.4) was plotted. Upon spraying for this test, the lacquer from the original can was exhausted

TEST 12 cont.

after nine bars had been sprayed, and the remaining three bars were sprayed with lacquer from an old can of Stresscoat. From the results obtained, this must have had a large effect upon the sensitivity because these three bars were entirely inconsistent with previous tests and with other bars of this test.

TEST 13.

The results fromthe preceding tests were so effective that it was believed that by using still higher temperatures and a slower rate of cooling, this sensitivity could be reached with coats of a lower regular sensitivity. With this in mind, coats 1201, 1203, 1205, and 1207 were used with 1207 being optimum. A drying temperature of 150 F was used, and the effects of air cooling and oven cooling were compared. For oven cooling, the oven was turned off, all vents were closed, and the oven was allowed to slowly cool to room temperature. The cooling curve for this condition is shown in figure 13. Cooling in air, 1205 crazed so that no reading could be taken, but cooling in the oven, it reached a sensitivity of 0.00015 in/in. It was interesting to note that this temperature had the effect of increasing the size and number of bubbles in the coating. This can be seen in fig. 14 if closely examined.

TEST 14.

From the preceding tests, it was apparent that each drying temperature had a definite numbered coat which would give a sensitivity on the order of 0.0002 in/in. It was decided to select four temperatures of 175 F, 150 F, 125 F, and 100 F and to determine the best coat for each of these temperatures. With these values, other optimum coats and corresponding drying temperatures could be approximated. With this

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TEST 14 cont.

in mind, 1201, 1202, 1203, and 1204 were used with 1207 being optimum. A drying temperature of 175 F was used and cooling was in the oven. Unfortunately, the oven control was faulty on this test, and the temperature rose to 195 F. Upon cooling in the oven, all coats crazed except 1201, and this coat crazed after being out of the oven for about 5 minutes. It was noted that the high temperature had formed a glaze on the surface of the lacquer giving it a glossy finish. There were very few bubbles except in the fairly thick parts of the coating. Also, the cracks which were formed by calibration were formed under this glossy coat and could not be dye etched. Dye etching under load had the same effect as dye etching an unstressed strip.

TEST 15.

Since Test 14 showed 1201 to be the best coat at 175 F, this coat was checked for dispersion. All twelve bars were prepared with 1201, and 1205 was the optimum. Ten of these were oven cooled to 84 F where it was found that six had crazed, and the remaining four were immediately removed and tested. It is to be noted that again the oven temperature rose above the setting, this time to 185 F, and also that the outside temperature was lower than for the previous test. The dispersion of the four specimens tested was very low, which is of course very desirable. The strain varied only from 0.00015 to 0.00016 in/in. Two of the bars were dried at room temperature, and the effect of the heat treatment can be seen from these results.

TEST 16.

Since only four values were obtained from Test 15, that run was repeated, and the oven carefully watched to insure that the 175 F temperature was not exceeded. None of the bars crazed, and some were

TEST 16 cont.

out of the oven an hour. This indicates that with a final testing temperature of about 77 F, 1201 is at an optimum using a temperature of 175 F. Dispersion on this test was also very low, sensitivity ranging from 0.00015 to 0.00016.

TEST 17

The next series of tests were at 150 F. With 1207 as optimum, 1203, 1204, 1205, and 1206 were used. This test indicated that 1204 was the coat giving the highest sensitivity without crazing. 1206 and 1205 were highly crazed.

TEST 18

With the information from test 17, it was desirable to check 1204 for dispersion. As a corallary to this, the effect of the thickness of the coatings was roughly determined. One coat was sprayed especially thick, and one coat especially thin, the rest being of the desirable thickness. The thin coat gave a relatively low sensitivity, while the thick coat gave extremely high sensitivity of 0.00001 with no craze. One bar of medium thickness was given rough treatment by dropping and jarring, and little effect was noted. The appearance of these various bars can be seen on figure 11. The bars were taken from the oven at 60 F, and four bars were broken after being removed for 0, 5, 7, and 10 minutes. After 10 minutes, the bars began to craze. The remainder of the bars were broken immediately after being removed from the oven, and except for the special coats already mentioned, the dispersion ranged from 0.00017 to 0.0002. It was also observed that the thicker coats besides being more sensitive gave most rapid and greater amount

TEST 18 cont.

of crazing. From this test it is apparent that for tests under 10 minutes with room temperature of about 72 F and oven temperature of 150 F, 1204 is the best coat. For higher room temperature, 1203 will prove optimum.

TEST 19

The next series of tests were at 125 F. With 1206 as optimum, 1206, 1207, 1208, and 1209 were used. 1208 and 1209 were crazed after cooling in oven to 78 F. 1206 and 1207 gave high sensitivity, but crazed after sitting in cool room of 68 F. For higher testing temperature, 1206 would not craze.

TEST 20

With the information of test 19, it was decided to use 1206 and check for dispersion. Since the outside (room) temperature was so cool, the strips were calibrated immediately, and the sensitivity ranged from 0.00012 to 0.00020, which quanitatively is small variation, but is a high percentage dispersion, in the order of 40% to 50%.

TEST 21

This test was at 100 F, and coats 1207, 1208, 1209, and 1210 were used with 1205 as the optimum. 1209 and 1210 tended to craze, while 1207 and 1208 were satisfactory. It was strange to note that 1207 was more sensitive than 1208.

TEST 22

With the above information it was decided to check 1208 and

TEST 22 cont.

1209 for dispersion, with 1205 as optimum, and drying temperature of 100 F. Upon cooling in the oven to 76 F, 1209 was all crazed, and two of 1206 indicated slight craze. The sensitivity of the 1208 ranged from 0.00016 to 0.00027 in/in, giving a dispersion of about 50%.

CREEP TESTS.

The technique of heat treatment brought up a new question, that of creep. The plastic property of the lacquer which causes the creep was discussed in the preceding section and will not be repeated here. The authors felt that the baking procedure would probably affect the creep of the coating both by hardening the coating and by increasing the sensitivity. It would seem that baking would reduce creep by reducing the plasticity of the lacquer. Since so little time was available the tests for creep after heating were not handled as well as they might have been. The tests were made in the calibration rig by loading the bar at varying rates and noting the time to reach full deflection. This was an unsatisfactory method, but time did not permit a more elaborate setup. The rate of loading was not constant as desired; times longer than 10 minutes were very difficult to obtain; and the test should have been pure tension rather than cantilever bending. However, a rough check of creep with optimum coat at 170 F, 150 F, and 125 F was all that was desired for this project, and a more thorough study is recommended in the future.

CREEP TEST 1-C

Twelve bars were prepared with coat #1201, dried in the oven at 170 F, and cooled in the oven to room temperature before testing.

CREEP TEST 1-C cont.

Tests were made at the following loading times, 0, 0, 0, 5, 13, 25, 40, 45, 70, 180, 270, 545 seconds. There was no creep. All values of strain recorded were within the normal dispersion range, and those at longer times were actually on the more sensitive side. Further tests should be made to check these results together with much slower rates of loading.

CREEP TEST 2-C

Twelve bars were prepared with coat #1203 and dried in the oven at 150 F, and cooled in the oven to room temperature before testing. Tests were made at the following times: 0, 0, 0, 5, 15, 60, 100, 200, 400, and 450 seconds. Again there was no creep. The specimens tested at 200 and 400 seconds had a sensitivity below 0.0001 in/in, but this was no doubt due to the fact that the coating was too thick. Two of the specimens tested at 0 seconds had a sensitivity of 0.00025 in/in, due to a very thin coating. This is another example of the effect of coat thickness on sensitivity.

CREEP TEST 3-C

Eleven bars were prepared with coat #1206. Eight were dried in the oven at 120 F, and cooled in the oven to room temperature before testing. Tests were made at the following times: 0, 0, 5, 30, 70, 150, 250, and 400 seconds. Again there was no creep.

Three bars were dried at room temperature and tested at the following times: 0, 0, and 70 seconds. The specimen did not crack in the 70 second loading test, since the sensitivity was greater than 0.0010 in/in. This illustrates the elimination of creep by heating.

CONCLUSIONS

The authors cannot support the claim of the manufacturer for the sensitization of brittle lacquer by dye etching under load. From the investigation reported herein, this claim seems extremely optimistic. On all tests, readings were taken before and after dye etching under load, and the sensitivity was never increased by the 0.0006 in/in promised. The normal increase was from 0.0002 to 0.0004 in/in, and this seemed to be of no value for a quantitative study. Figure 10 shows the effect of dye etching under load, and this is a slight indication of the difficulty of determining the critical strain which is so important in a quantitative analysis. This illistration shows the dye etched pattern when used with and without the heat treatment, and it can be seen that the cracks grade into preferred orientation of the craze which grades into random craze. This preferred orientation might be of some value in an analysis to locate the position of the strain pattern, but for any use much experience is required for the use of the dye etchant. After several weeks of constant use of this technique, the two authors would vary considerably in reading a strip, and when a third experienced party was called in, the difference was even greater. Thus from the results obtained in these tests, the authors cannot substantiate the claims of the manufacturer.

The results from the investigation of the possibilities of heat treatment were very encouraging, and this technique is believed to be of great practical use in the field of stress analysis. With the limited apparatus available to the authors, strains of the order of 0.00015 were measured consistently, drying craze was eliminated entirely, and creep with slow rates of loading was eliminated.

For the maximum sensitivity with heat treatments, the specimens

must be cooled sufficiently after being removed from the oven. The cooling rate affects crazing and sensitivity, and it is regretted that available equipment allowed only two cooling rates, cooling in air and cooling in the oven (fig. 13). Cooling in the oven at the slower rate reduced crazing and increased sensitivity more than cooling at the faster rate.

For every coating there seems to be an optimum temperature for drying, or, in other words, for every oven temperature there is an optimum coating which gives the greatest sensitivity without crazing. The minimum value of strain that the authors were able to obtain with no crazing was from 0.00010 to 0.00015 in/in, and this sensitivity was obtained with several coatings by using different drying temperatures. For steel with a modulus of elasticity of 30,000,000, this value of strain corresponds to 3000 - 4500 p.s.i.

Time was not available for a complete study of dispersion and expected error, but from the tests made, the dispersion is greatly reduced by using a low numbered coating and drying at a high temperature. Using coating 1201 dried at 170 F and cooled in the oven, sixteen tests gave readings from 0.00015 to 0.00016. This is an error of only 300 p.s.i. when steel is used. With normal air drying methods giving sensitivity of 0.0008 in/in, the 15% error promised by the manufacturer means an error of 3600 p.s.i. when steel is used. This indicates that heat treatment also increases the accuracy of the results obtained by Stresscoat analysis, however, many more tests must be made to prove this large increase in accuracy.

Outside temperature and humidity conditions seem to have no effect on the coating during heat treatment. However, the temperature of the specimen at the time of the test is important. Sensitivity and crazing depend largely on the thickness of the coating. Heavy coats

are more sensitive and craze more quickly than light coats as seen in figure 11. The most satisfactory method of obtaining uniform thickness of coat at all times is to spray all specimens to the same color, a dark yellow. The lower numbered coats being thinner are more easily sprayed and control of thickness is much better than with higher numbers. Downhand spraying was found to be more satisfactory than horizontal for spraying the thinner coats which run excessively.

It might be well to note here that some old cans of Stresscoat were found to be much less sensitive than newer ones of the same number. This might have been due to evaporation or to some unknown additions to the can. However, it is felt that a warning to future users might be in order.

Another big advantage seems to have been found for the heat treatment - that of eliminating creep. A few very rough tests were made to get an idea of the effect of creep on baked specimens under slow application of load, and the results showed not a trace of creep with loading times up to ten minutes. This promises to be an easy solution to the problem of creep, and if further investigations can substantiate this theory, the process of heat treatment will gain added importance.

An investigation was conducted by A. S. Waters and D. K. Marquardt to determine the value of heat treatment on more complicated structures (10). The results which will not be produced here tend to confirm the results obtained by the investigation of the authors.

A summary of the advantages of heat treatment over other methods of sensitizing shows that: (1) Heat treatment seems to be the only method applicable to an investigation to determine the first crack in a structure being slowly loaded. (2) Heat treatment seems

to be the only method applicable to an investigation to determine a low strain from a load which is quickly applied and removed. (3) Heat treatment is the only method offering control of sensitivity at low values of strain for a quantitative analysis. (4) Heat treatment is the only method found to eliminate creep and drying craze.

The following is a table of drying temperatures for four grades of Stresscoat with testing temperature of 75 F:

#1201	170 F
#1203	150 F
#1206	125 F
#1208	100 F

The drying temperature may be slightly higher for higher testing temperature and lower for lower testing temperatures. Control of sensitivity may be had by varying the drying temperature for a given coat or by varying the coat for a given drying temperature. Coat #1201 at 170 F gave the least dispersion.

RECOMMENDATIONS

The authors regret that more time was not available to continue this work to completion. The results obtained from this investigation which was so limited by time and equipment seem to indicate that a more thorough study with well controlled conditions of outside temperature and humidity, oven temperature and humidity, and cooling rate would be of great benefit to the field of stress analysis. It is recommended that further investigation be made to find the exact optimum baking temperature for each coat together with the dispersion for each and the optimum cooling rate to the testing temperature. The authors feel that a shorter drying time might be coupled with a much longer cooling time to give better results. The heat treatments should be further investigated on complicated shapes and on materials other than steel. A correction factor for applying to results obtained using a steel calibration strip in conjunction with a structure of some material having a different thermal coefficient of expansion would undoubtedly be of great value. Refrigeration after drying and before stressing the coating should be investigated (9), but at present this is limited to qualitative work only. Other ideas might be found in the publications listed in the bibliography.

TEST I

When sprayed: dry bulb - 74
wet bulb - 61

When stressed: dry bulb - 75
wet bulb - 61

Optimum coating - #1205

All specimens dried at room temperature 24 hours, stressed, and etched under load.

Coat Number	Sensitivity Before Etch	Sensitivity After Etch
1203	0.00122	0.00100
1203	.00118	.00090
1203	.00108	.00085
1205	.00080	.00050
1205	.00080	.00053
1205	.00080	.00050
1205	.00085	.00048
1205	.00080	.00051
1205	.00088	.00055
1207	.00078	.00040
1207	.00080	.00038
1207	.00075	.00040

REMARKS: Viewed through a magnifying glass under strong light, very faint craze marks oriented normal to the direction of principal stress were found in the etched specimens. The end of these marks was very difficult to distinguish, and the value of the sensitivity is quite arbitrary. The value of this etchant on complicated shapes seems questionable.

TEST 2

When sprayed: dry bulb - 75
wet bulb - 61

When stressed: dry bulb - 77
wet bulb - 64

Optimum coating - #1205

All specimens dried at room temperature 24 hours, stressed, and etched under load.

Coat Number	Sensitivity Before Etch	Sensitivity After Etch
1205	0.00088	0.00047
1205	.00085	.00065
1205	.00085	.00045
1205	.00086	.00060
1205	.00105	.00065
1205	.00095	.00057
1207	.00080	.00065
1207	.00090	.00065
1207	.00075	.00040
1209	.00095	.00065
1209	.00055	.00030
1209	.00067	.00040

TEST 3

When sprayed: dry bulb - 77
wet bulb - 64

When stressed: dry bulb - 78
wet bulb - 65

Optimum coating - #1206

All specimens dried at room temperature 24 hours, stressed, and etched under load.

Coat Number	Sensitivity Before Etch	Sensitivity After Etch
1206	0.00085	0.00045
1206	.00090	.00040
1206	.00082	.00050
1206	.00105	.00055
1208	.00080	.00035
1208	.00082	.00033
1208	.00078	.00030
1211	.00070	.00040
1211	.00070	.00030
1211	.00080	.00040

Two specimens were sprayed with #1206 and dried in oven at 100°F for 24 hours. They were removed from oven and cooled in air for the times shown before stressing, and load etched.

Time Cool In Air	Sensitivity Before Etch	Sensitivity After Etch
1 min.	0.00085	0.00045
15 min.	.00045	.00025

REMARKS: Oven temperature during drying varied from 98°F to 103 F, and specimens were cooled in air by placing on table away from air currents. Etching time was decreased markedly.

TEST 4

When sprayed: dry bulb - 78
wet bulb - 71

When stressed: dry bulb:- 78
wet bulb - 67

Optimum coating - #1206

Two specimens dried at room temperature 24 hours, stressed, and etched under load.

Coat Number	Sensitivity Before Etch	Sensitivity After Etch
1206	0.00102	0.00075
1206	.00105	.00070

Ten specimens dried in oven at 100 F for 24 hours, cooled in air for the times indicated before testing, and etched under load. Coat #1206 was used throughout.

Time Cool In Air	Sensitivity Before Etch	Sensitivity After Etch
0 min.	0.00090	0.00050
0 min.	.00095	.00060
2 min.	.00072	.00050
4 min.	.00062	.00050
5 min.	.00080	.00060
6 min.	.00060	.00041
8 min.	.00060	.00040
10 min.	.00061	.00050
12 min.	.00055	.00035
14 min.	.00058	.00036

REMARKS: Curve of Sensitivity vs. Cooling Rate is fig. 3.

TEST 5

When sprayed: dry bulb - 78
wet bulb - 67

When stressed: Dry bulb - 78
Wet bulb - 71

Optimum coating - #1207

Specimens were dryed in oven @ 100 F, air cooled for times shown before stressing, and etched under load.

Coat Number	Time Cool in Air	Sensitivity Before Etch	Sensitivity After Etch
1209	0 min.	0.00100	0.00055
1209	5 min.	.00060	.00040
1209	10 min.	.00055	.00025
1209	15 min.	.00035	Off scale
1207	0 min.	.00090	.00052
1207	10 min.	.00050	.00030
1207	20 min.	.00060	.00030
1207	30 min.	.00050	Off scale

Specimens were dried at room temperature, 24 hours, stressed and etched under load.

Coat Number	Sensitivity Before Etch	Sensitivity After Etch
1209	0.00075	0.00050
1209	.00090	.00090
1207	.00085	.00045
1207	.00085	.00070

TEST 6

When sprayed: dry bulb - 78
wet bulb - 71

When stressed: dry bulb - 77
wet bulb - 62

Optimum coating - #1208

All specimens were sprayed with coat 1208, ten dried in oven at 100 F for 24 hours, and two were dried at room temperature for 24 hours. All were dye etched under load.

Time Cool In Air	Sensitivity Before Etch	Sensitivity After Etch
0 min.	0.00080	0.00060
3 min.	.00065	.00040
6 min.	.00050	.00040
9 min.	.00025	.00025
12 min.	.00035	.00030
15 min.	.00030	off scale
20 min.	.00020	.00020
25 min.	.00024	.00020
30 min.	.00020	.00018
40 min.	.00020	.00020
Air dried	.00080	.00045
Air dried	.00070	.00035

REMARKS: Readings lower than 0.0004 in/in were below scale and were extrapolated. Error is probably very high since small distance gives a large change in strain reading.

TEST 7

When sprayed: dry bulb - 74
wet bulb - 70

When stressed: dry bulb - 76
wet bulb - 66

Optimum coating - 1207

All specimens are coating 1209. Ten specimens were dried in oven at 100 F for 24 hours, cooled in still air for times indicated, stressed, and etched under load. Two specimens were dried at room temperature for 24 hours, stressed, and etched under load.

Time Cool In Air	Sensitivity Before Etch	Sensitivity After Etch
0 min.	0.00090	0.00052
3 min.	.00080	.00030
6 min.	.00050	.00018
9 min.	.00038	.00018
12 min.	.00036	.00015
15 min.	.00038	.00015
20 min.	.00023	.00015
25 min.	.00029	.00016
30 min.	.00022	.00014
40 min.	.00020	.00010
Air dried	.00100	.00067
Air dried	.00110	.00065

REMARKS: Curve of Sensitivity vs. Cooling Rate is fig.

TEST 8

When sprayed: dry bulb - 74
wet bulb - 66

When stressed: dry bulb - 74
wet bulb - 72

Optimum coating - #1206

All specimens were dried in oven at 120 F for 24 hours, cooled in still air for times indicated, stressed, and etched under load.

Time Cool In Air	1208	1206
20 min.	0.00017	0.00020
25 min.	.00017	.00022
30 min.	.00017	.00027
35 min.	.00018	.00025
40 min.	.00017	.00028
50 min.	.00017	.00020

REMARKS: The etchant showed no increase in sensitivity. Coating 1208 gives much less dispersion, but it crazed so that it is not recommended for use on complicated shapes.

TEST 9

When sprayed: dry bulb - 74
wet bulb - 72

When stressed: dry bulb - 78
wet bulb - 70

Optimum coating - #1208

All specimens were dried in oven at 90 F for 24 hours, cooled in still air for 20 min, and stressed.

1206	1208
0.00073	0.00057
.00075	.00060
.00067	.00058

1209	1211
0.00055	0.00048
.00060	.00047
.00062	.00047

TEST 10

When sprayed: dry bulb - 78
wet bulb - 70

When stressed: dry bulb - 77
wet bulb - 67

Optimum coating - #1208

All specimens were dried in oven at 110 F for 24 hours, cooled in still air 20 minutes and stressed.

1206	1208
0.00030	0.00020
.00050	.00015
.00050	.00017

1209	1211
0.00027	CRAZED
.00040	
.00024	

TEST 11

When sprayed: dry bulb - 77
wet bulb - 67

When stressed: dry bulb 80
wet bulb 68

Optimum coating - #1207

All specimens were dried in oven at 100 F for 24 hours, cooled in still air 20 minutes, and stressed.

1206	1208
0.00048	0.00038
.00042	.00038
.00040	.00037

1209	1211
0.00028	0.00025
.00028	.00027
.00030	.00022

TEST 12

When sprayed: Dry bulb - 80
Wet bulb - 68

When stressed: Dry bulb - 79
Wet bulb - 67

Optimum coating - #1208

Time cool In Air	Sensitivity
5 min.	0.00045
7 min.	.00042
10 min.	.00035
12 min.	.00035
15 min.	.00030
20 min.	.00025
20 min.	.00030
30 min.	.00028
40 min.	.00045
50 min.	.00045
60 min	.00048
Air dried	.00065

REMARKS: Samples tested at 40, 50, and 60 minutes were sprayed with lacquer from an old can of Stresscoat. This apparently had a definite effect on the sensitivity. Curve of Sensitivity vs. Cooling time is figure 4.

TEST 13

When Sprayed: dry bulb - 79
wet bulb - 67

When Stressed: Dry bulb - 78
wet bulb - 65

Optimum coating - #1207

All specimens were dried in oven at 150 F. Six were removed, cooled in still air for 25 minutes and stressed.

Coat Number	Sensitivity
1201	0.00030
1201	.00030
1203	.00030
1205	Crazed
1205	Crazed
1207	Crazed

Six were cooled in oven to 80 F and stressed.

1201	0.00030
1203	.00020
1203	.00019
1205	.00015
1207	Crazed
1207	Crazed

REMARKS: To cool in oven, oven was turned off and closed up. After about 2 hours the temperature had dropped to 80 F, and specimens were tested.

TEST 14

When sprayed: dry bulb - 79
wet bulb - 66

When stressed: dry bulb - 77
wet bulb - 65

Optimum coating - #1207

All specimens were dried at 175 F, cooled in oven, and stressed.

1201	1202
0.00023	0.00020
.00025	craze
.00022	craze

1203	1204
C R A Z E	C R A Z E

REMARKS: Oven temperature rose to 195 F during the night. All coats had a glazed finish with very few bubbles. Cracks formed under the surface, and etching had no effect on the strain pattern. Coat 1201 also crazed after setting at room temperature for about 5 minutes.

TEST 15

When sprayed: dry bulb - 72
wet bulb - 63

When stressed: dry bulb - 73
wet bulb - 63

Optimum coating - #1205

All specimens were prepared with coat 1201, dried in oven at 175 F, cooled in oven, and stressed.

Number	Sensitivity
1	0.00016
2	.00016
3	.00015
4	.00015
6 to 10	All crazed

Two specimens of coat 1201 were dried at room temperature.

Number	Sensitivity
1	0.00102
2	.00098

REMARKS: Six of the samples crazed in the oven when the temperature reached 84 F. The other four were removed and broken immediately. Again the oven temperature climbed above the setting, this time to 185 F, and again the glossy coat was formed on all bars.

TEST 16

When sprayed: dry bulb - 72
wet bulb - 64

When stressed: dry bulb - 74
wet bulb - 65

Optimum coating - #1205

All specimens were prepared with coat 1201, dried in oven at 175 F, cooled in oven, and stressed.

Number	Sensitivity
1	0.00015
2	.00015
3	.00015
4	.00015
5	.00015
6	.00015
7	.00015
8	.00016
9	.00016
10	.00016
11	.00016
12	.00016

REMARKS: The same glossy coat was obtained as in Tests 14 and 15.

TEST 17

When sprayed: dry bulb - 77 wet bulb - 65	When stressed: dry bulb - 74 wet bulb - 65

Optimum coating - #1207

All specimens were dried in oven at 150 F, cooled in oven, and stressed.

1203	1204
0.00022	0.00019
.00020	.00018
.00022	.00020

1205	1206
C R A Z E	C R A Z E

TEST 18

When sprayed: dry bulb - 74
wet bulb - 65

When stressed: dry bulb - 72
wet bulb - 64

Optimum coating - #1205

All specimens were prepared with coat 1204, dried in oven at 150 F, cooled in oven, and stressed.

Number	Sensitivity
1	0.00018
2	.00018
3	.00018
4	.00015
5	.00018
6	.00021
7	.00017
8	.00018
9	.00021
10	.00010

REMARKS: Coatings began to show some crazing after about 15 minutes after removal from oven. Specimen 9 is the thin coat shown in figure 11, and specimen 10 is the thick coat shown in the same photograph. One specimen was handled roughly for 20 minutes. It crazed slightly, but did not harm the reading. The sensitivity was 0.00017, and the photograph is figure 11.

TEST 19

When sprayed: dry bulb - 72	When stressed: dry bulb - 70
wet bulb - 64	wet bulb - 63

Optimum coating - 1206

All specimens were dried in oven at 125 F, cooled in oven, and stressed.

1206	1207
0.00015	0.00015
.00015	.00015
.00015	.00018

1208	1209
C R A Z E	C R A Z E

REMARKS: All crazed after sitting in cool room for about 15 minutes.

TEST 20

When sprayed: dry bulb - 70
wet bulb - 63

When stressed: dry bulb - 71
wet bulb - 63

Optimum coating - #1205

All specimens were prepared with coat 1206, dried in oven at 125 F, scoled in oven, and stressed.

Number	Sensitivity
1	0.00012
2	.00012
3	.00015
4	.00015
5	.00016
6	.00017
7	.00017
8	.00017
9	.00017
10	.00018
11	.00019
12	.00020

TEST 21

When sprayed: dry bulb - 71
wet bulb - 63

When stressed: dry bulb - 72
wet bulb - 63

Optimum coating - #1205

Coat Number	Remarks	Sensitivity
1207	Air cooled from 95 F	0.00021
1207	Air cooled from 88 F	0.00019
1207	Air cooled from 80 F	0.00018
1208	Air cooled from 95 F	0.00021
1208	Air cooled from 88 F	0.00020
1208	Air cooled from 80 F	0.00020
1209	Air cooled from 95 F	Crazed
1209	Stressed at 90 F	0.00020
1209	Stressed at 80 F	0.00015
1210	Air cooled from 95 F	Crazed
1210	Stressed at 90 F	0.00030
1210	Stressed at 80 F	0.00017

All specimens were dried in oven at 100 F, cooled in oven to temperatures shown and stressed or air cooled to room temperature and stressed as noted.

TEST 22

When sprayed: dry bulb - 72
wet bulb - 63

When stressed: dry bulb - 72
wet bulb - 64

Optimum coating - 1205

All specimens were dried in oven at 100 F, cooled in oven, and stressed.

1208	1209
0.00016	ALL CRAZED
.00025	
.00022	
.00027	
.00021	
.00019	

REMARKS: It is believed that coat 1209 crazed because of the low testing temperature because in previous tests it was all right.

CREEP TEST 1

All specimens were prepared with coat 1201, dried at 170 F, cooled in oven to room temperature, and loaded in the times indicated.

Time of Loading	Sensitivity
0 min.	0.00015
0 min.	.00015
0 min.	.00017
5 sec.	.00015
13 sec.	.00017
25 sec.	.00017
40 sec.	.00014
45 sec.	.00013
70 sec.	.00013
180 sec.	.00016
270 sec.	.00014
540 sec.	.00013

CREEP TEST 2

All specimens were prepared with coat 1203, dried at 150 F, cooled in oven to room temperature, and loaded in times indicated.

Time of Loading	Sensitivity
0 sec.	0.00020
5 sec.	.00014
15 sec.	.00014
15 sec.	.00016
60 sec.	.00015
100 sec.	.00020
200 sec.	.00010
400 sec.	.00013
450 sec.	.00010

REMARKS: Specimens for run of 200 seconds and 450 seconds were very thick coats. This accounts for the low strain reading.

CREEP TEST 3

All specimens were prepared with coat 1206, dried at 125 F, cooled in oven to room temperature, and loaded in times indicated.

Time of Loading	Sensitivity
0 sec.	0.00030
0 sec.	.00032
5 sec.	.00030
30 sec.	.00040
70 sec.	.00023
150 sec.	.00040
250 sec.	.00031
400 sec.	.00040

Three specimens were dried at room temperature and loaded in times indicated.

0 sec.	.00075
0 sec.	.00070
70 sec.	no crack at .00100

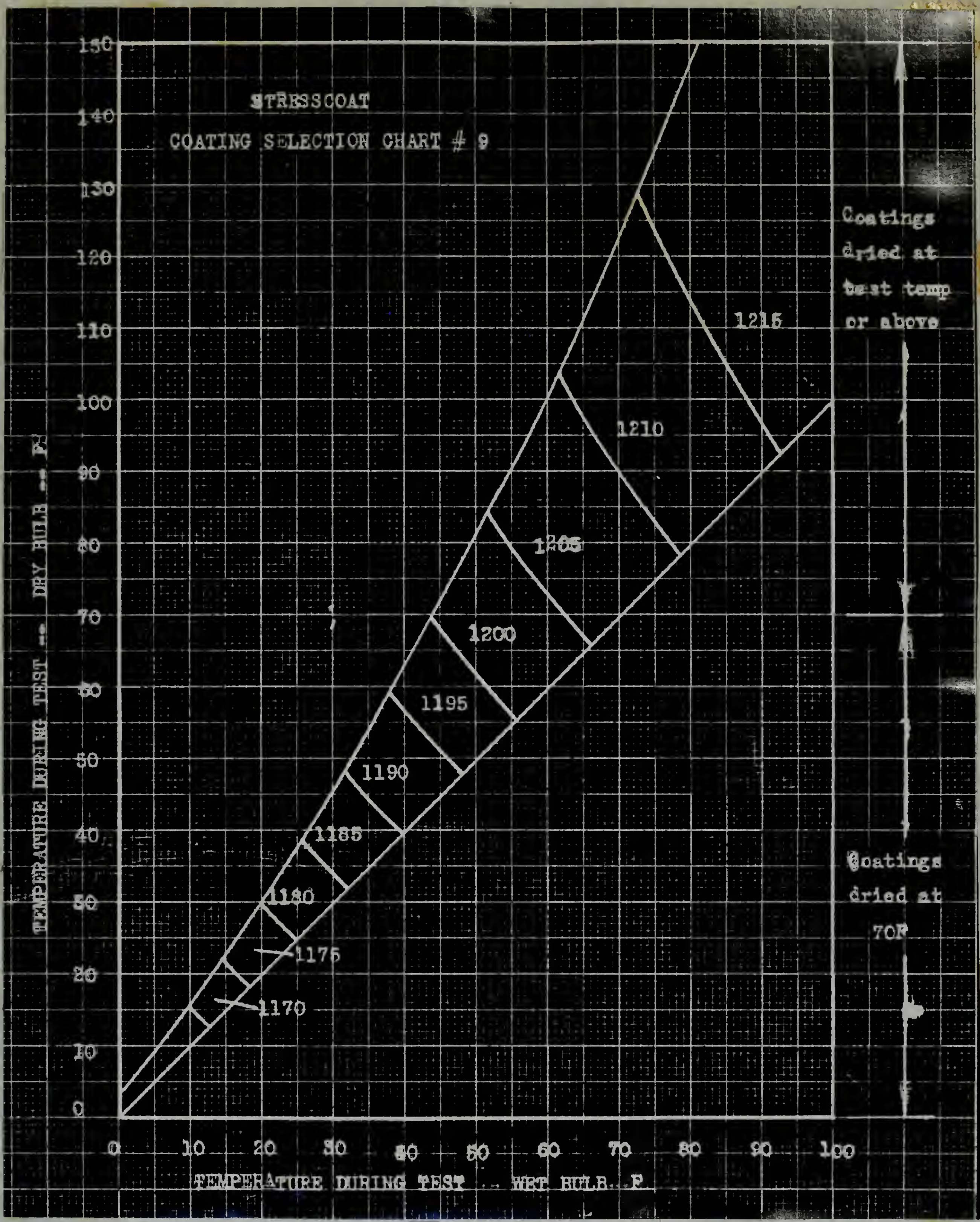
STRESSCOAT
COATING SELECTION CHART # 9
TEMPERATURE DURING TEST -- DRY BULB -- F
TEMPERATURE DURING TEST -- WET BULB F
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
1170
1175
1180
1185
1190
1195
1200
1205
1210
1215
Coatings dried at test temp or above
Coatings dried at 70F

Fig. 1

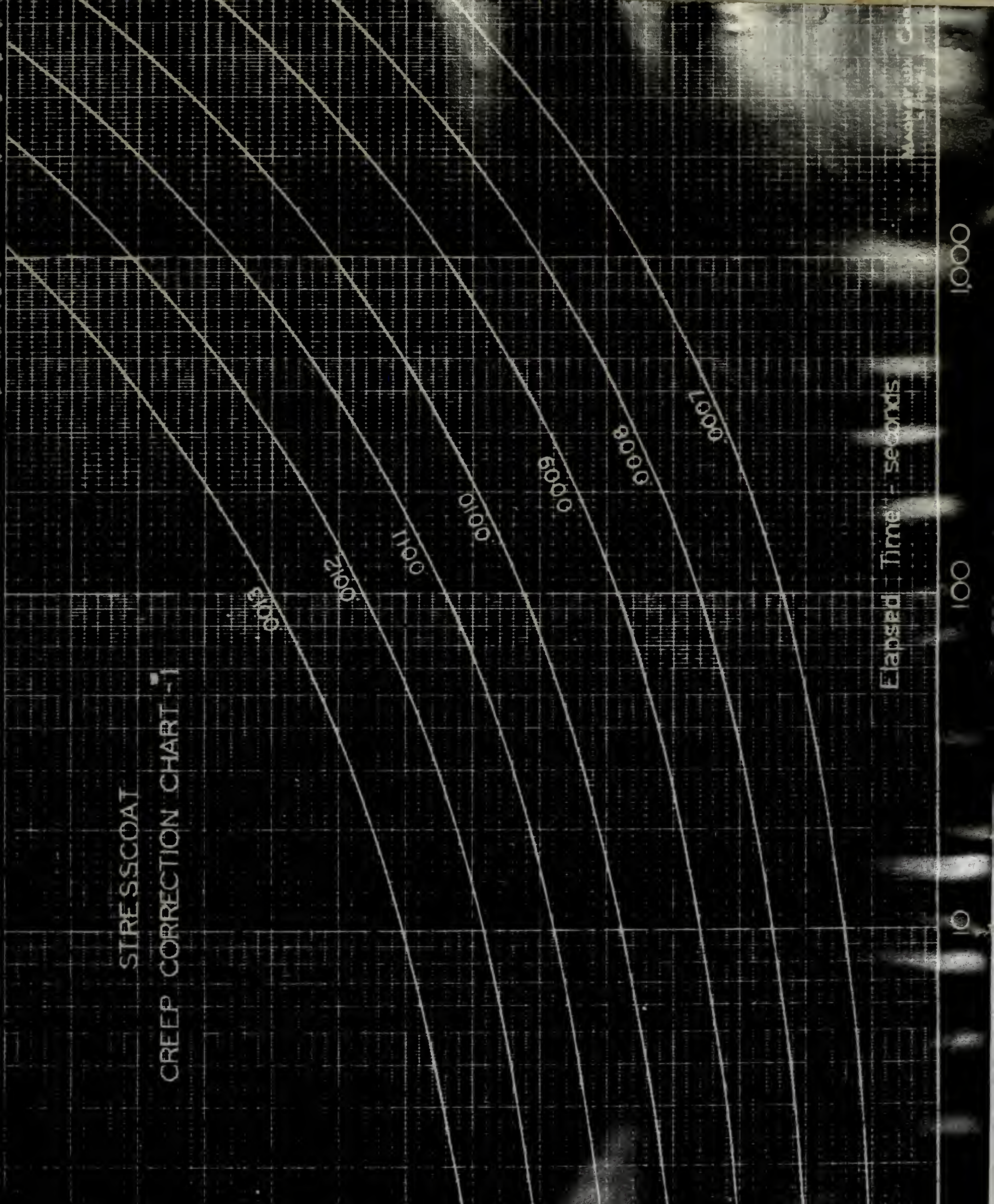
STRESSCOAT
CREEP CORRECTION CHART -1
Strain - in per in x 10⁴
Elapsed Time - seconds
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
10
100
1000

Fig. 2

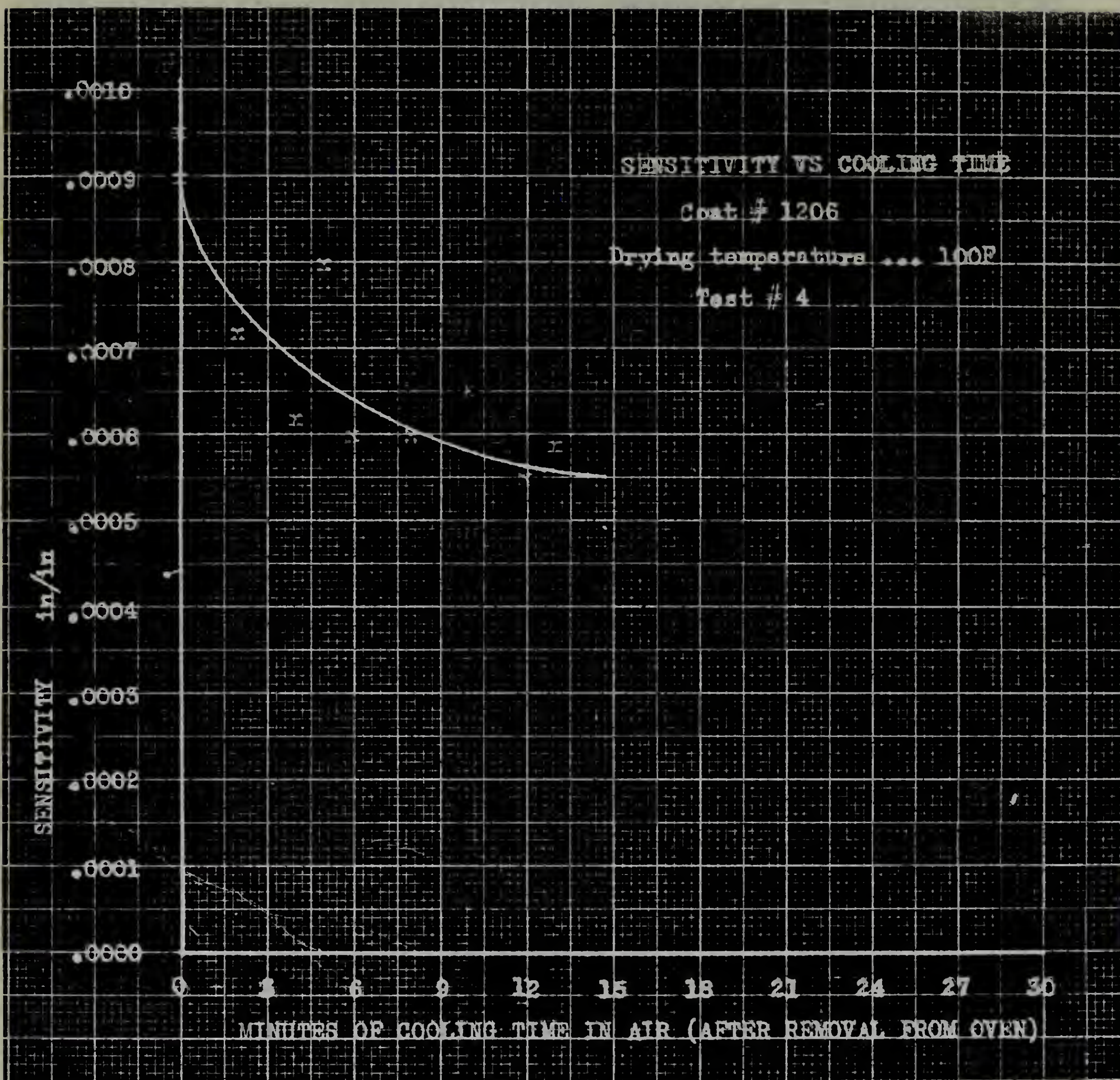
SENSITIVITY VS COOLING TIME
Coat # 1206
Drying temperature ... 100F
Test # 4
.0010
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.0000
SENSITIVITY in/in
0
3
6
9
12
15
18
21
24
27
30
MINUTES OF COOLING TIME IN AIR (AFTER REMOVAL FROM OVEN)

Fig. 3

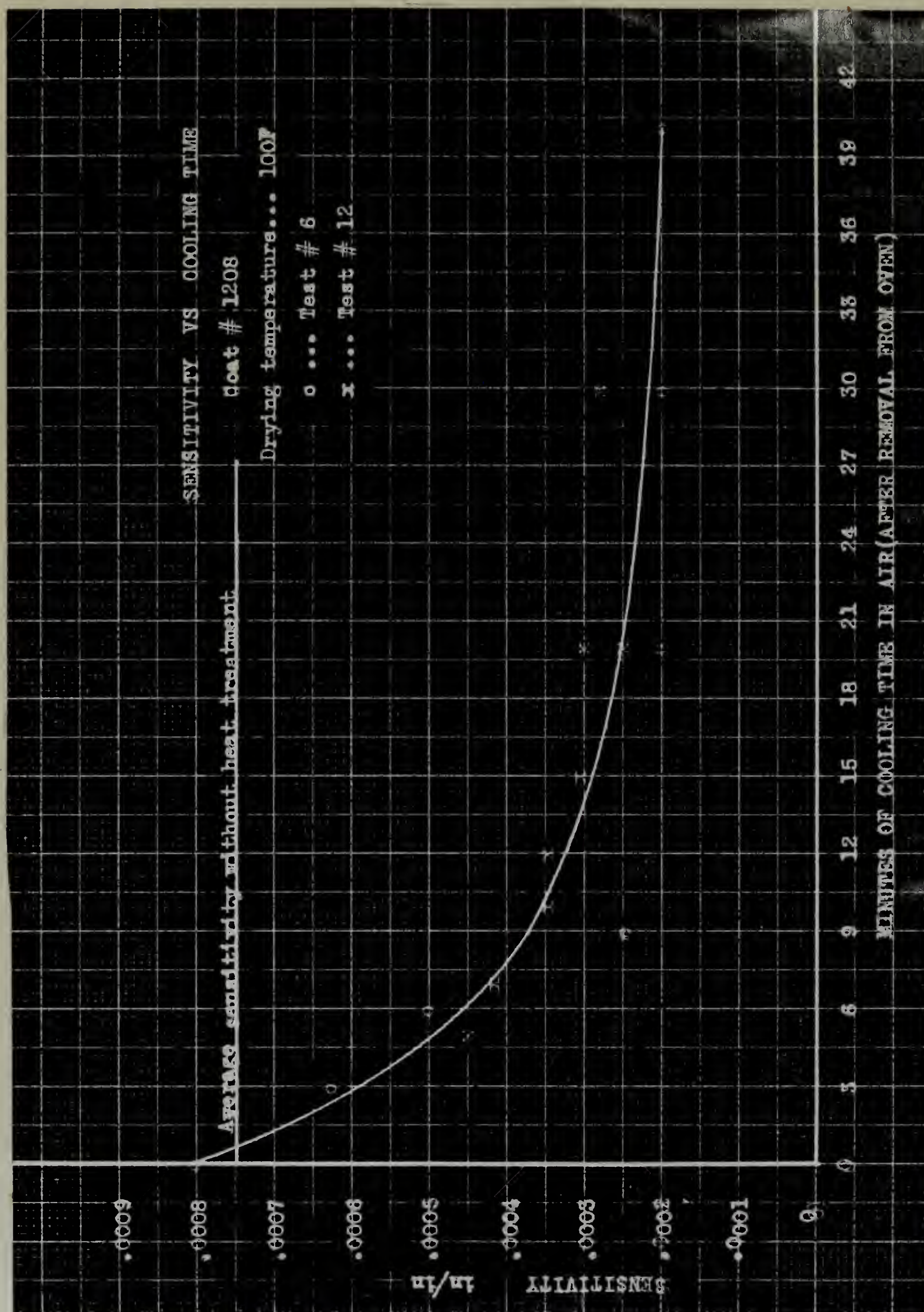
SENSITIVITY VS COOLING TIME
Coat # 1208
Drying temperature.... 100F
o ... Test # 6
x ... Test # 12
Average sensitivity without heat treatment
MINUTES OF COOLING TIME IN AIR(AFTER REMOVAL FROM OVEN)
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
SENSITIVITY in/in
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
0

Fig. 4

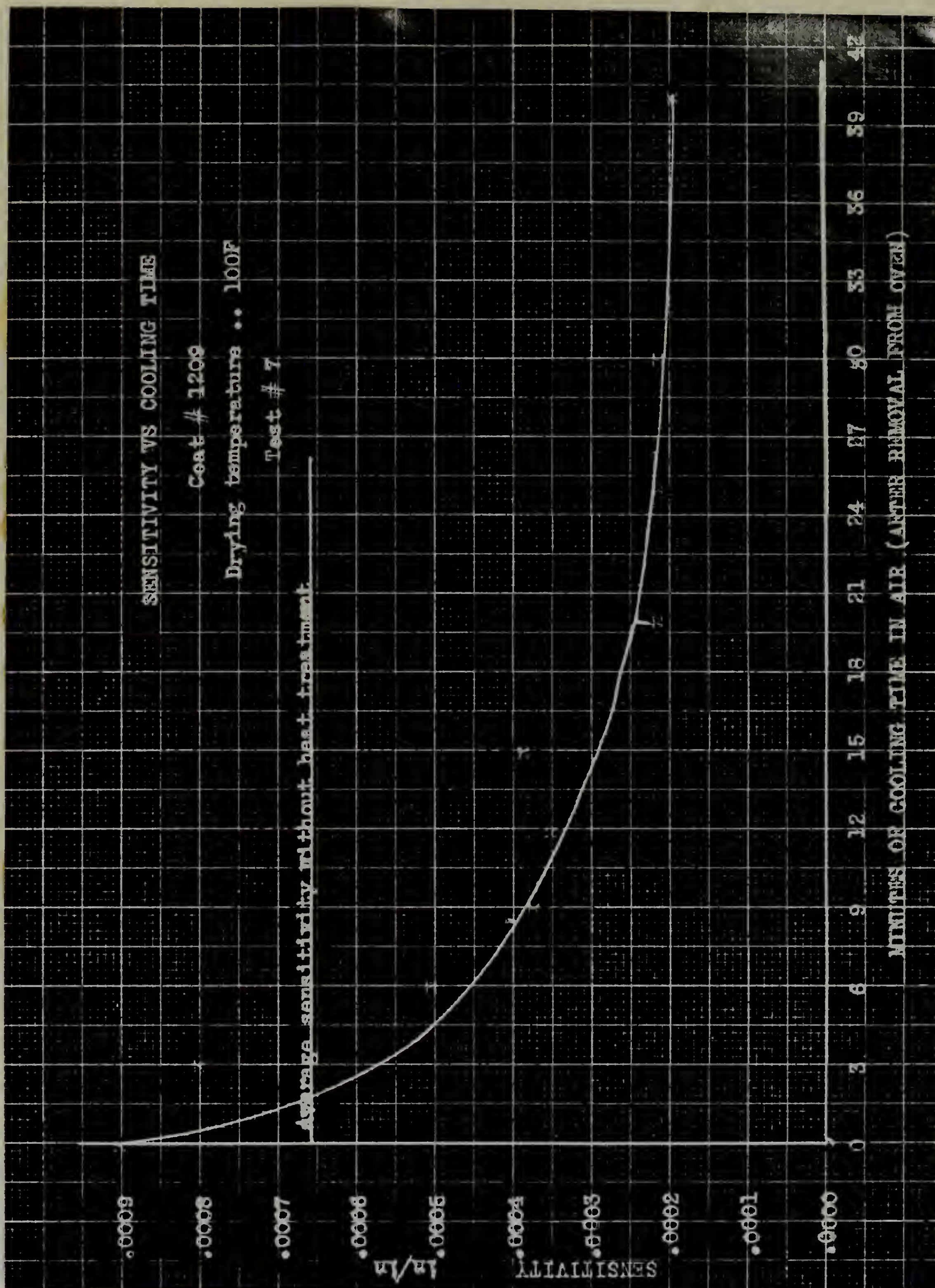
SENSITIVITY VS COOLING TIME
Coat # 1209
Drying temperature .. 100F
Test # 7
Average sensitivity without heat treatment
SENSITIVITY in/in
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
.0000
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
MINUTES OF COOLING TIME IN AIR (AFTER REMOVAL FROM OVEN)

Fig. 5

Fig. 6 CANTILEVER LOADING DEVICE

This shows a calibration bar supported at the left end, and bearing up against the cam on the right end. The adjusting screw is seen on the top of the left end. This is the unstrained position of the bar.

Fig. 7 CANTILEVER LOADING DEVICE

This shows calibration bar in loaded position. This gives known strains along bar surface.

Fig. 6 CALIBRATION SCALE

This scale is calibrated to read strains along bar as caused by cantilever loading device. The bar is placed in scale as shown, and the lowest crack in the coating is a measure of the sensitivity of the coating.

Fig. 9 DRYING CRAZE

This photo shows the effect and appearance of drying craze. The left bar was heat treated before calibration. The two on the right were dried in air before calibration. The baked bar shows no drying craze and givês good crack delineation. The drying craze on the other two almost obliterated the strain cracks giving poor appearance, less accuracy, and less sensitivity.

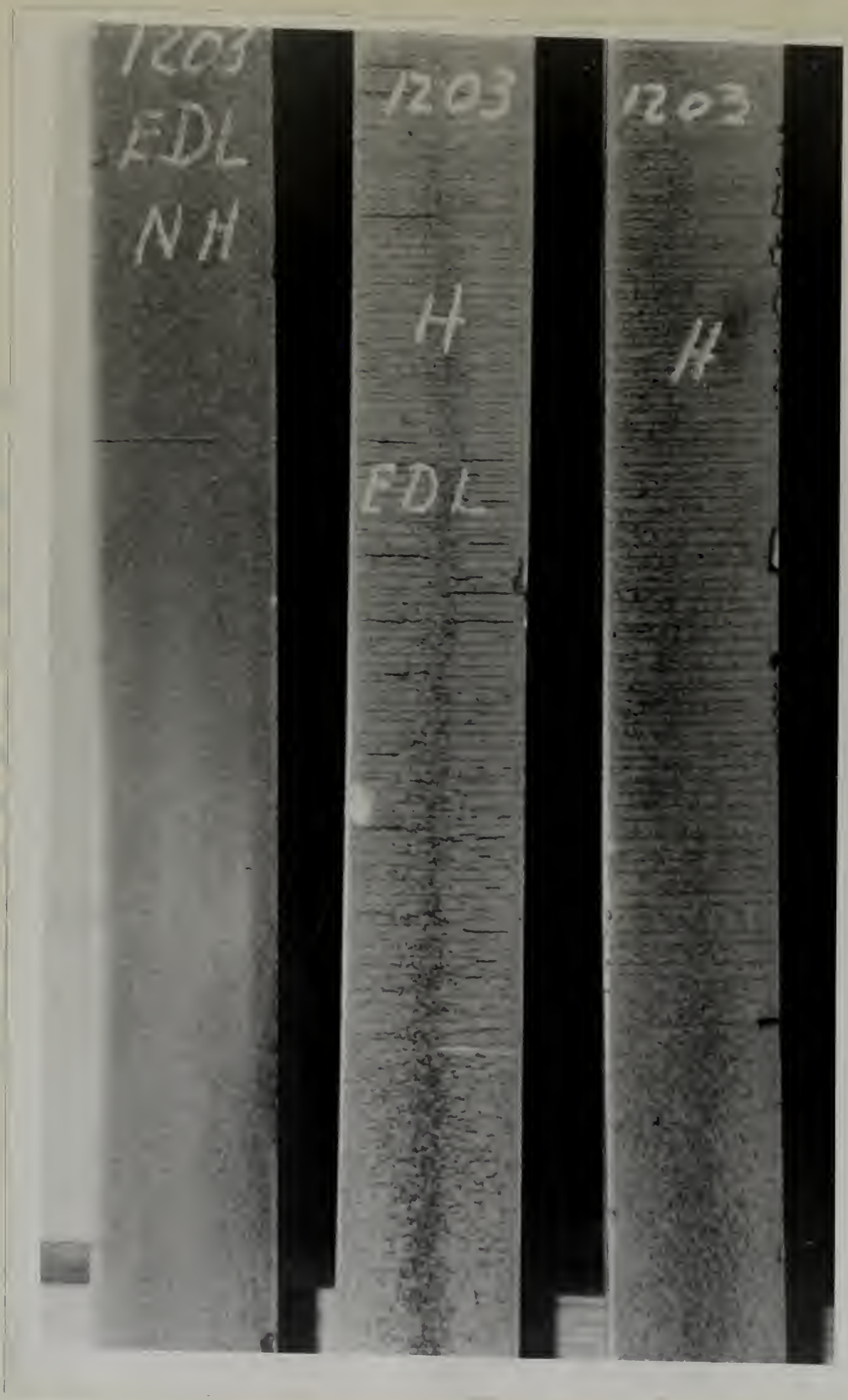

FIGURE 10

(Explanation on next page)

Fig. 11 VARIATION OF SENSITIVITY BY COAT THICKNESS

All bars were sprayed with coat #1203, and dried at 150 F. The thick coat gives the easiest and most sensitive reading, and the bubbles caused by heat treatment can be seen in this coat. The strip marked "R" was given light impact by dropping. Strip "10" was out of the oven 10 min. before testing, strip "R", 20min., and all others, tested immediately.

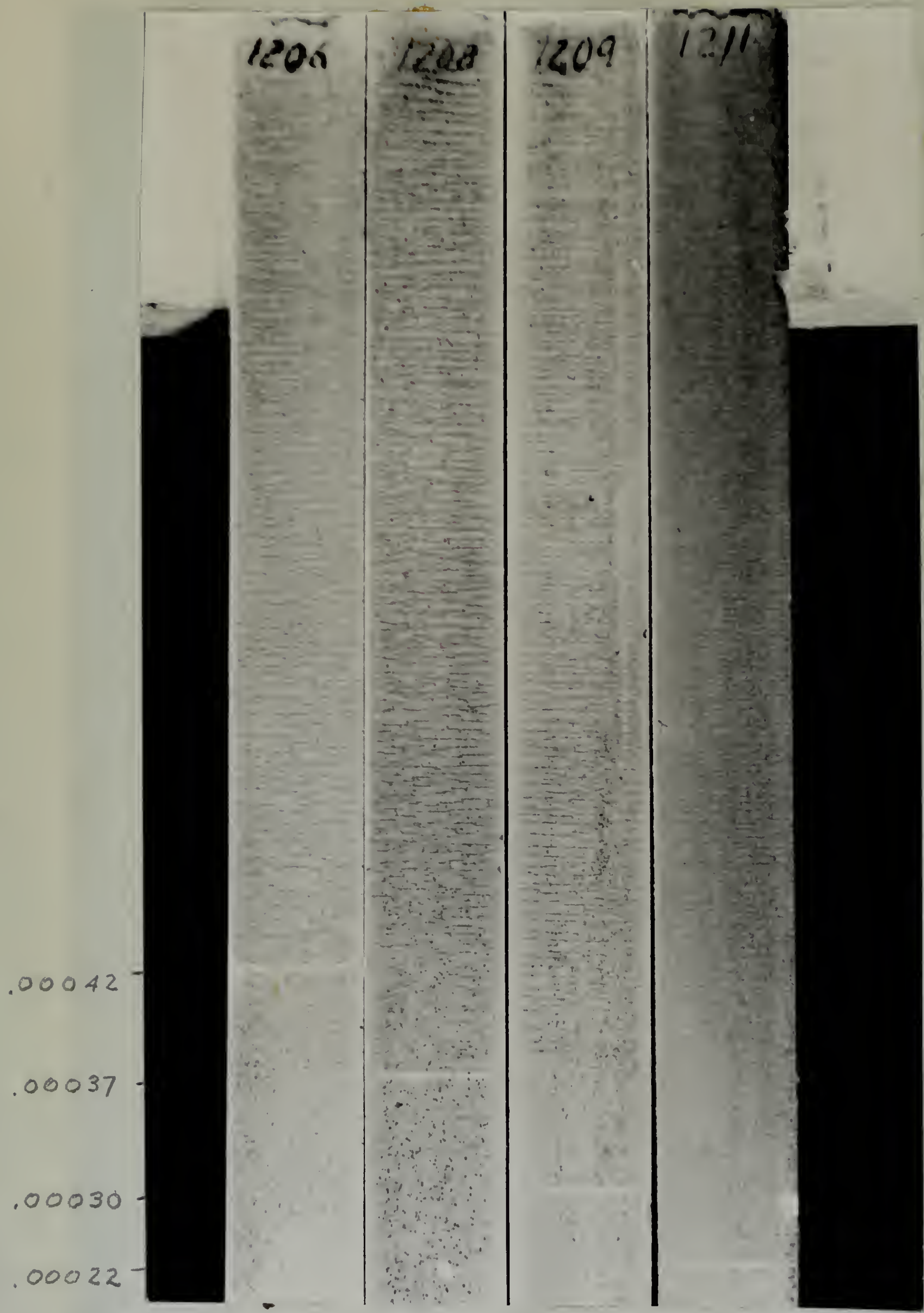

Fig. 12 VARIATION OF SENSITIVITY BY COAT SELECTION

These four specimens were dried for 24 hours at 100 F, and were cooled in air 20 minutes before testing. White marks indicate strain readings, and the values of these readings are indicated.

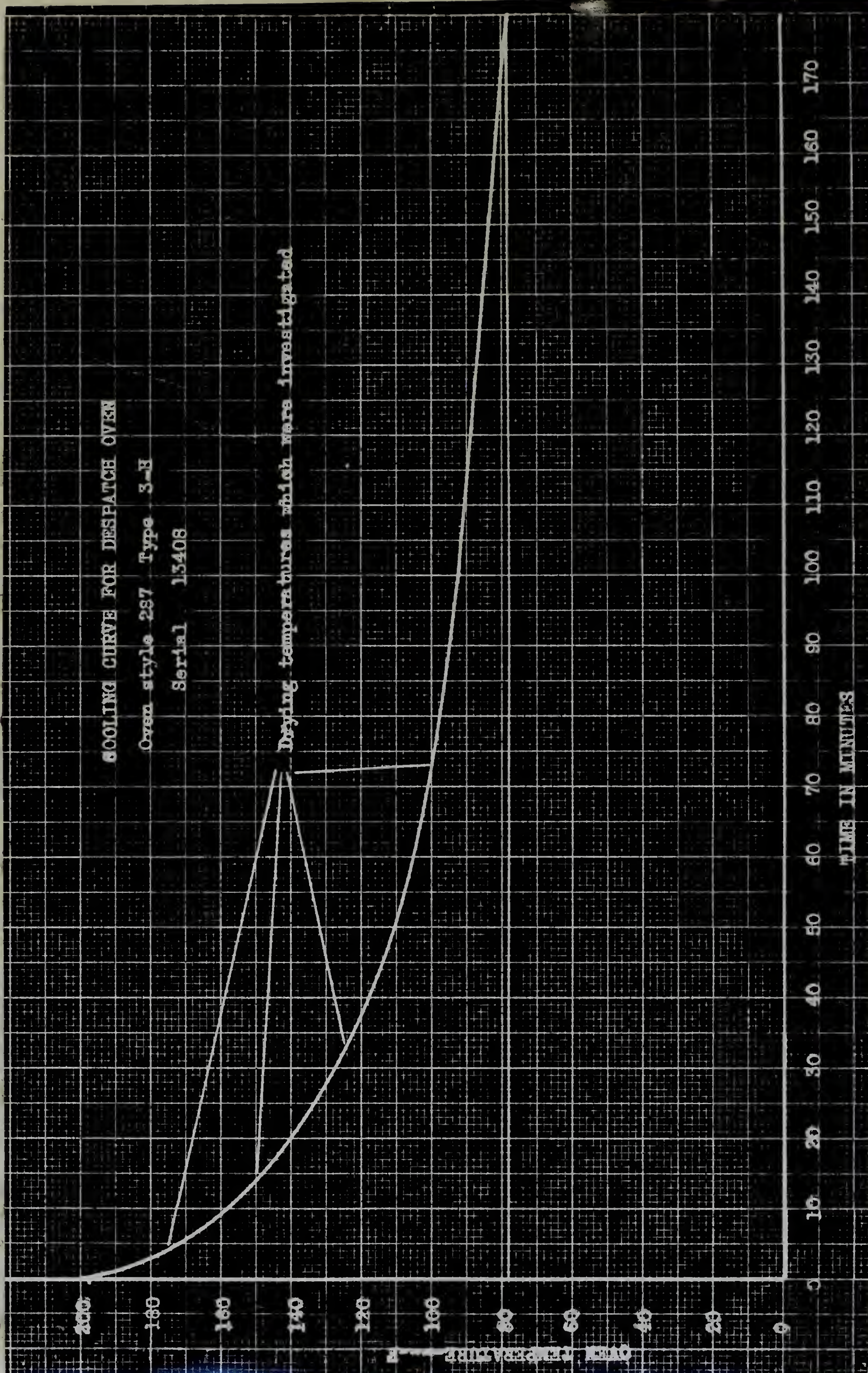
COOLING CURVE FOR DESPATCH OVEN
Oven style 287 Type 3-H
Serial 13408
Drying temperatures which were investigated
TIME IN MINUTES
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
0 20 40 60 80 100 120 140 160 180 200

Fig. 13

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